Optothermal stability of large ULE and Zerodur mirrors

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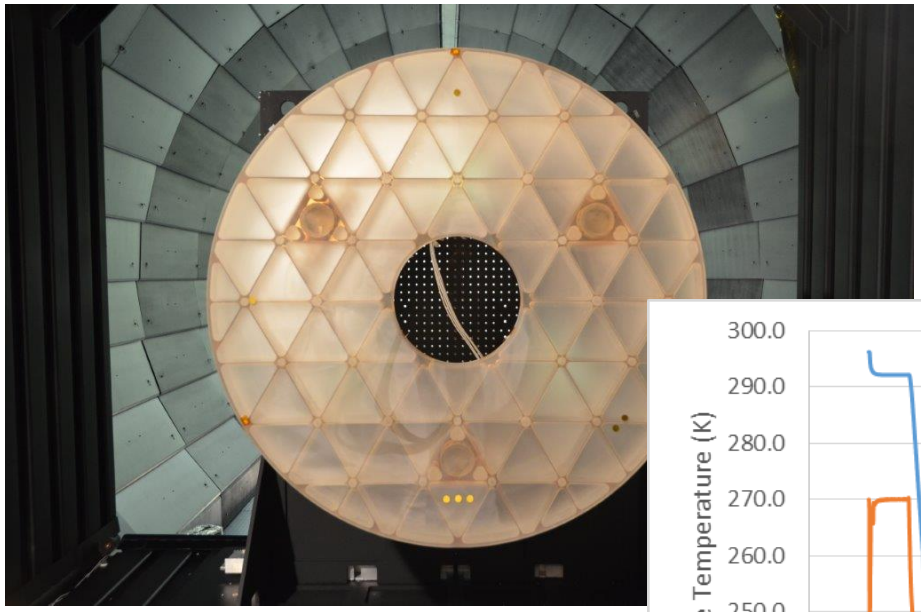
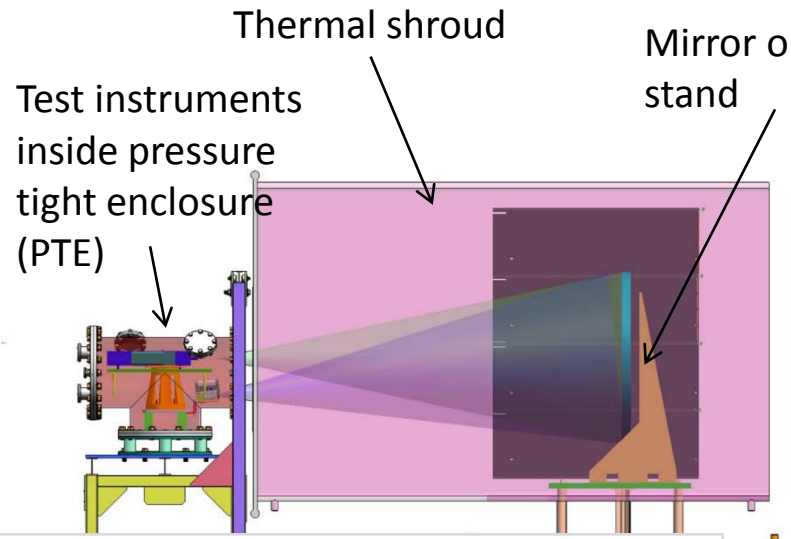
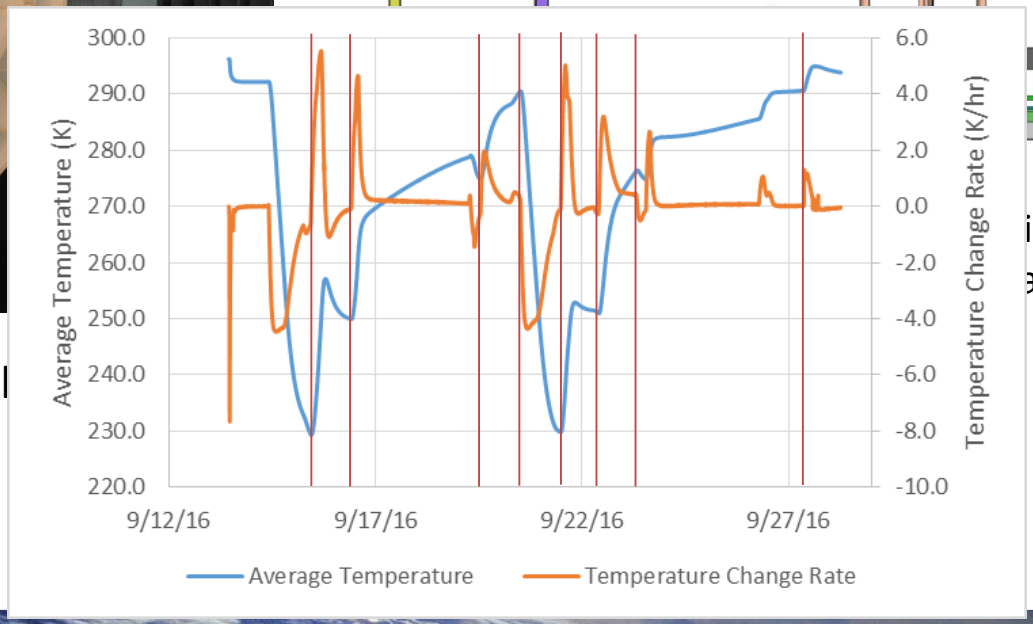
Optothermal test of Zerodur Mirror

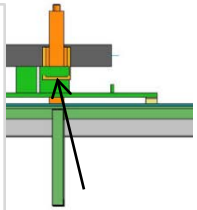
1.2m Zerodur Mirror
1.06m measured aperture
0.071m and 0.124m thick at the ID and OD respectively



Surface figure measurements tal
275, 250 and 230K.



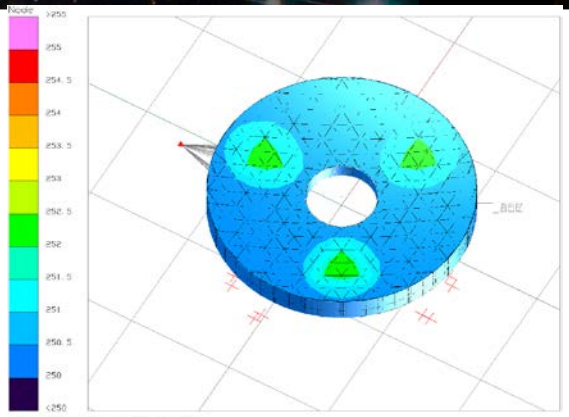


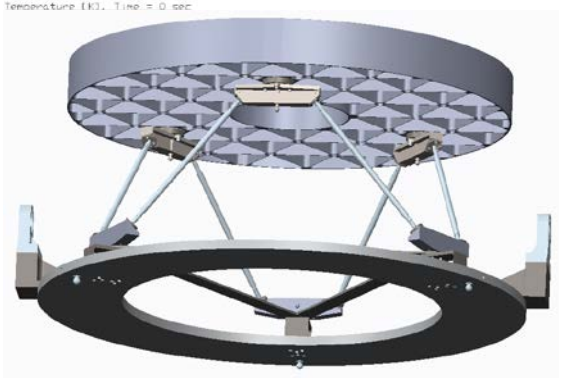


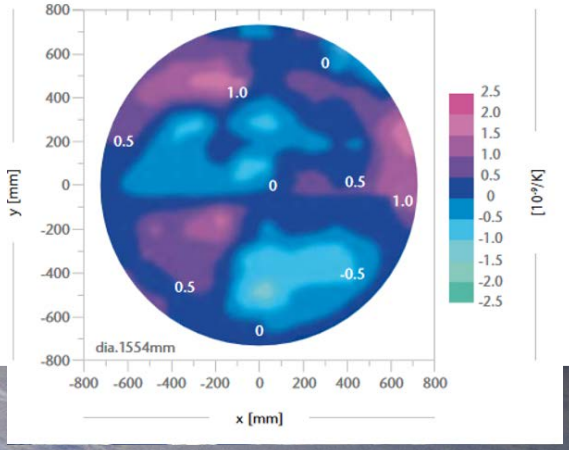
ignment
age

Surface Figure Error (SFE) Sources

- Error due to Thermal Gradients
  - Thermal gradients cause mirror to bend
  - Caused by non-zero CTE and gradients
- Error due to Mount Effects
  - Mirror mount not athermalized, but very compliant flexures
  - Hexapod legs grow and bend mirror
- Error due to CTE inhomogeneity
  - CTE gradients + isothermal temperature change bend the mirror
- Test Setup Error



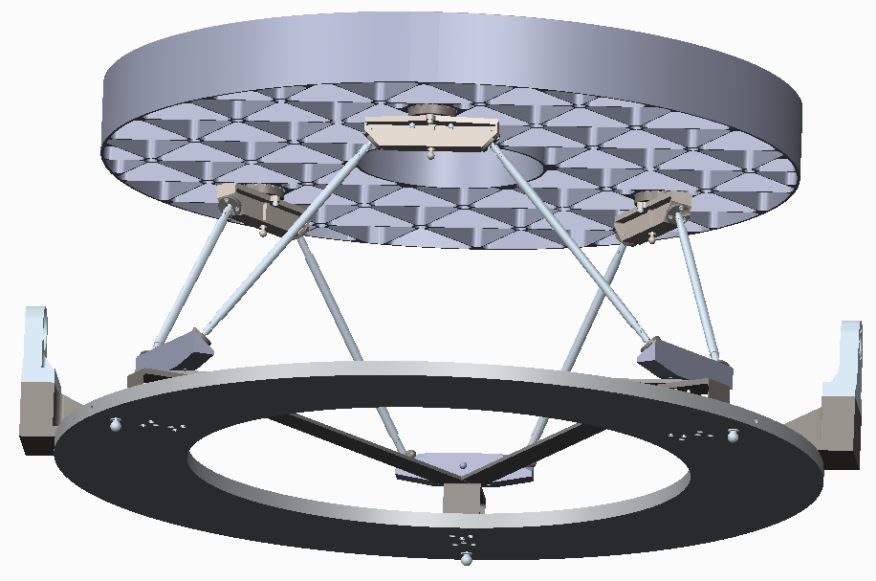


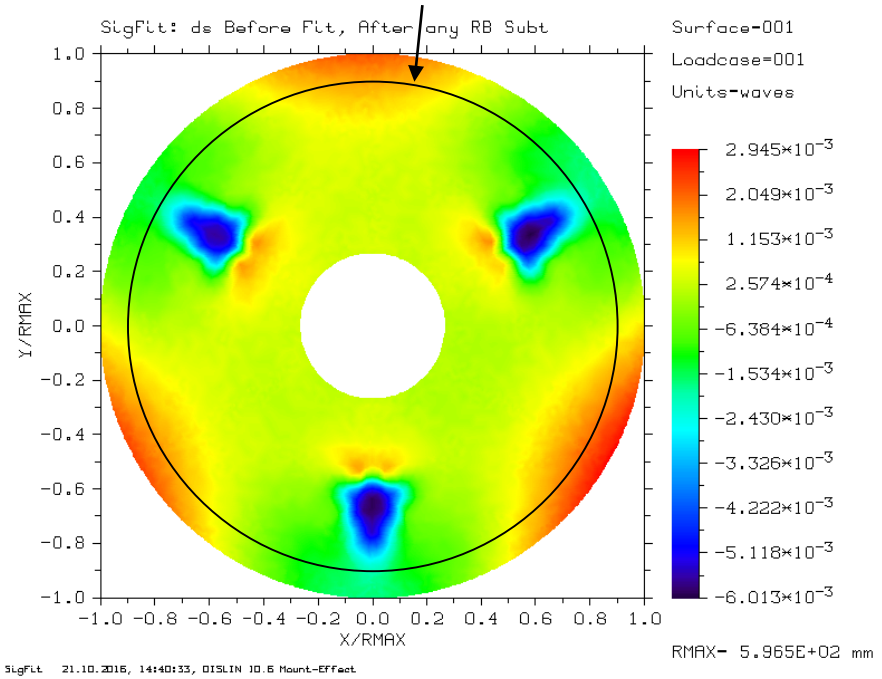


Zerodur SFE due to Mount

- RMS SFE = 0.81nm

The test was sub-aperture and only the area enclosed in the circle was measured





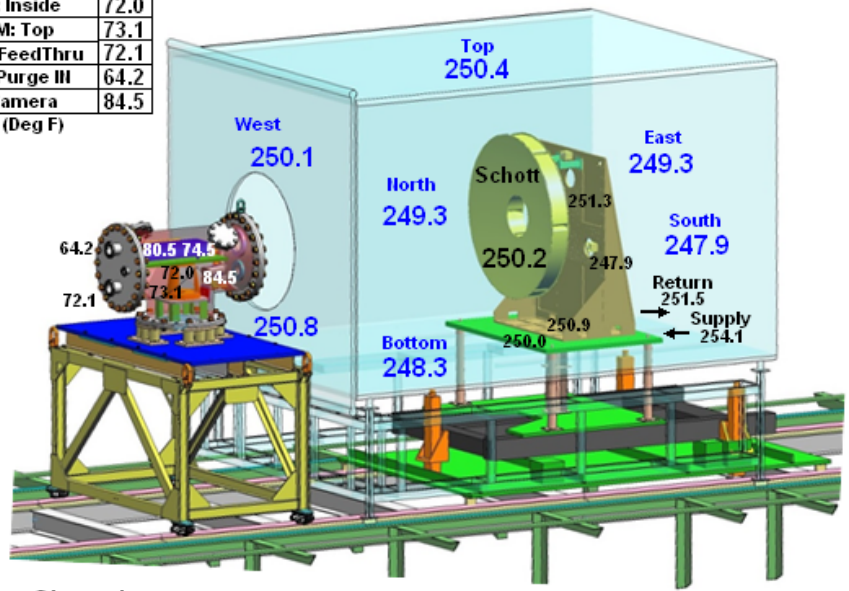
Zerodur Test Measured Data at 250K

09/16/16 08:10:57

AMTD2 / Schott Cryo Test

PTE	
PhaseCam East	74.5
PhaseCam West	80.5
PTE: Inside	72.0
ADM: Top	73.1
Cable FeedThru	72.1
PTE: Purge IN	64.2
IR Camera	84.5

(Deg F)

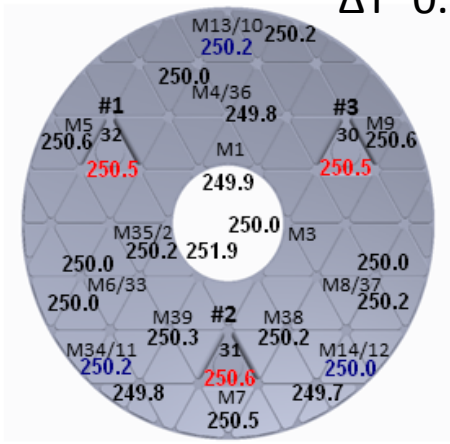


Shroud	
Top	250.4
North	249.3
South	247.9
Bottom	248.3
West Top	250.1
West Bottom	250.8
East	249.3

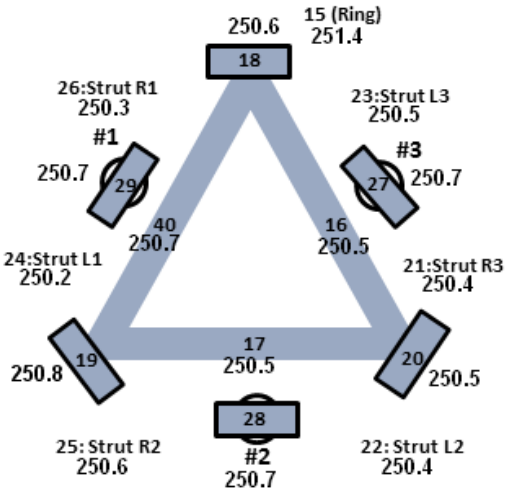
(Kelvin)

Shroud			Schott		
Average	249.4	K	Average	250.2	K
Rate	-0.1	K/HR	Rate	-0.1	K/HR
Max	250.8	K	Max	251.9	K
Min	247.9	K	Min	249.7	K
Grad	3.0	K	Grad	2.2	K

ΔT~0.8K*



North (Front View) South



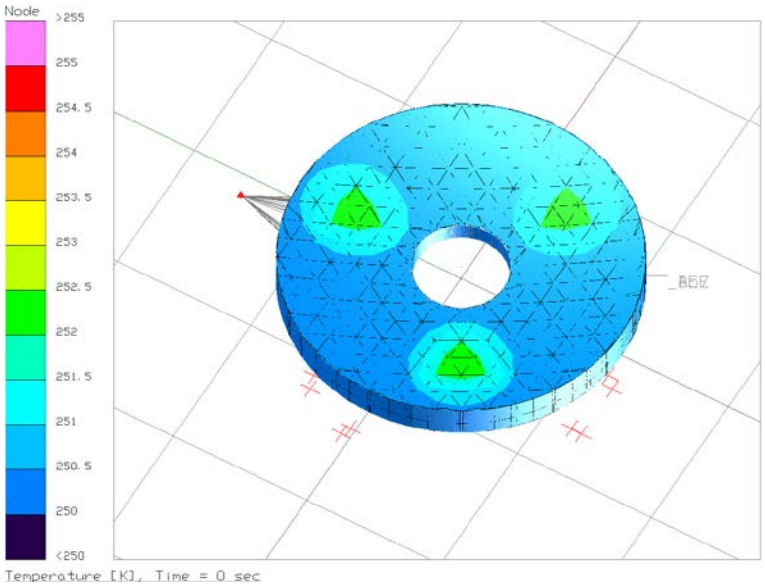
M1- Top Hole	249.9
M2 - North Hole	251.9
M3 - South Hole	250.0
M4 - 12:00	250.0
M5 - 10:00	250.6
M6 - 8:00	250.0
M7 - 6:00	250.5
M8 - 4:00	250.2
M9 - 2:00	250.3
M10- Top Edge	250.2
M11 - 8:00 Edge	249.8
M12 - 4:00 Edge	249.7
M13 - Top Front	250.2
M14 - 4:00 Front	250.0
M33 - 8:00 (w/M6)	250.0
M34 - 8:00 (w/M11)	250.2
M35 - 8:00 (w/M2)	250.2
M36 - 12:00 (w/M4)	249.8
M37 - 4:00 (w/M8)	250.0
M38 - 5:00	250.2
M39 - 7:00	250.3
30 - South Pad	250.5
31 - Bottom Pad	250.6
32 - North Pad	250.5
15 - 12:00 Ring	251.4
16 - Delta_3	250.5
17 - Delta_2	250.5
18 - Top Bracket	250.6
19 - South Bracket	250.8
20 - North Bracket	250.5
21 - Strut R3	250.4
22 - Strut L2	250.4
23 - Strut L3	250.5
24 - Strut L1	250.2
25 - Strut R2	250.6
26 - Strut R1	250.3
27 - South Mount	250.7
28 - Bottom Mount	250.7
29 - North Mount	250.7
40 - Delta_1	250.7

(Kelvin)

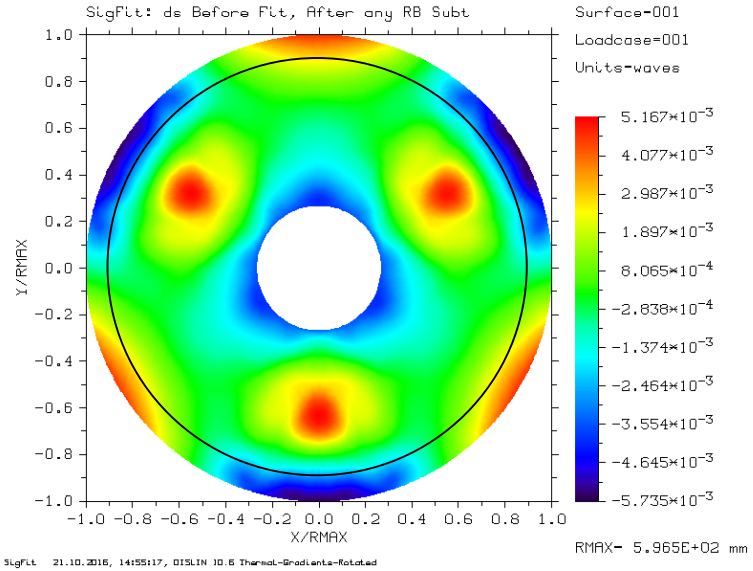
*Likely anomalous measurement ignored

Zerodur SFE due to Thermal Gradients

Potential Temperature Gradients



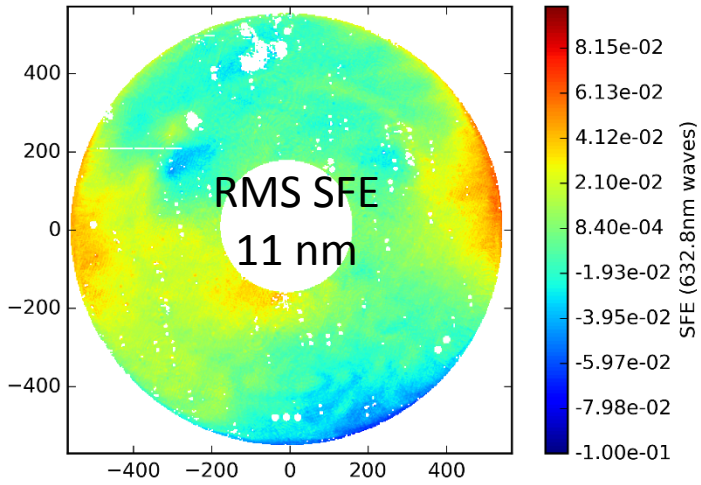
SFE due to T gradients



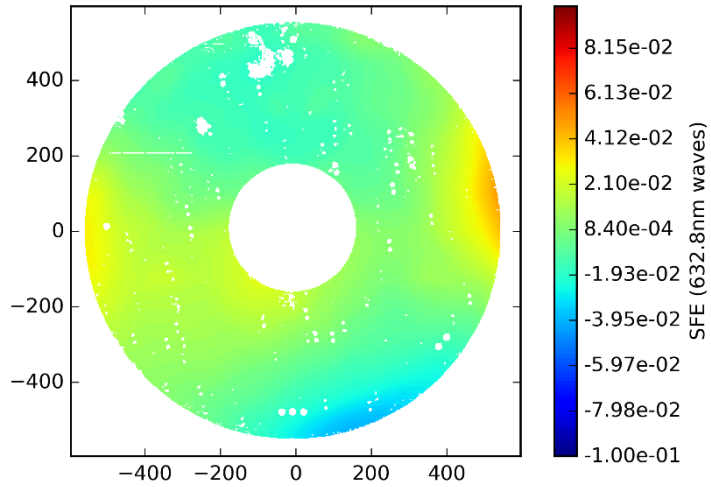
RMS SFE = 1.28nm

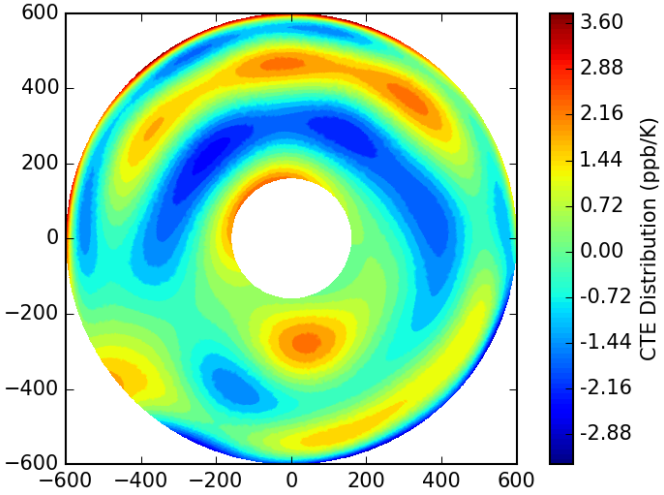
Test and Correlation Delta

Measured soak effect

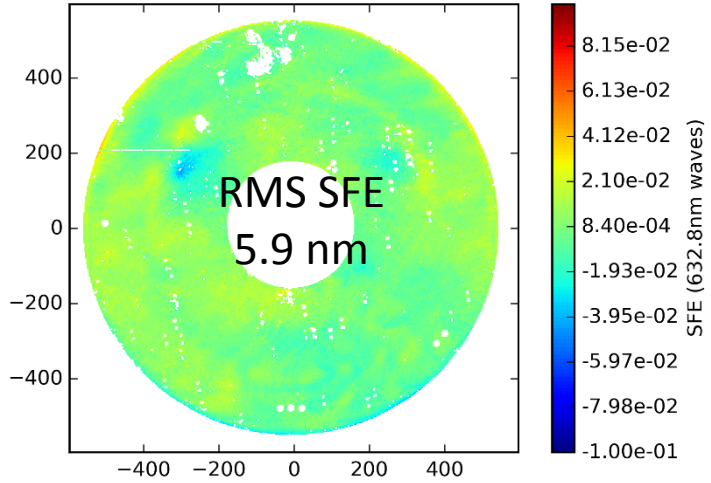


Analysis soak effect





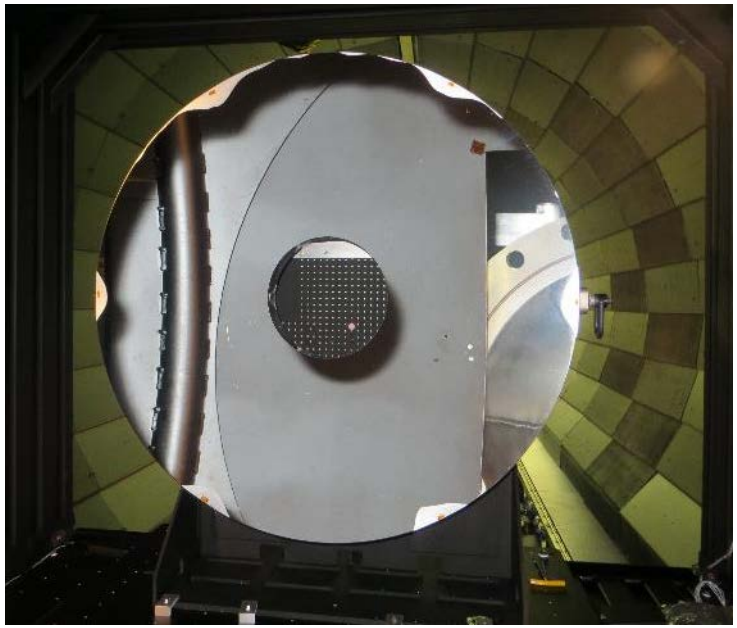
CTE Map with ~6.5ppb/K CTE homogeneity

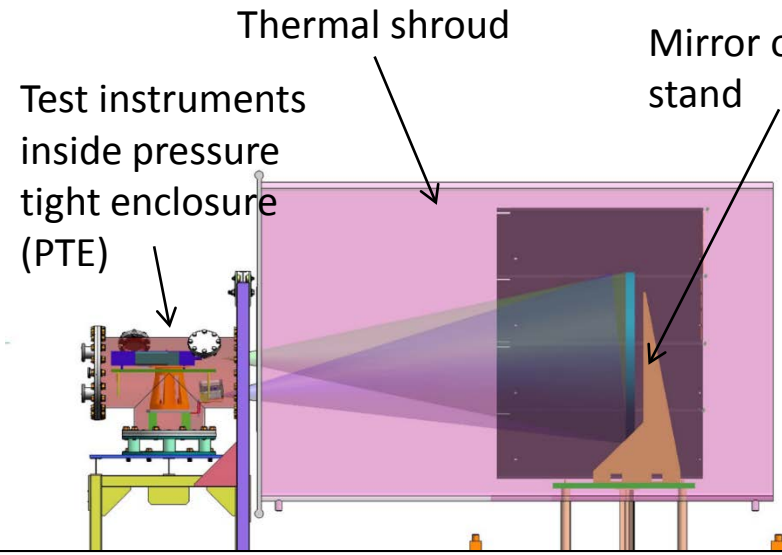


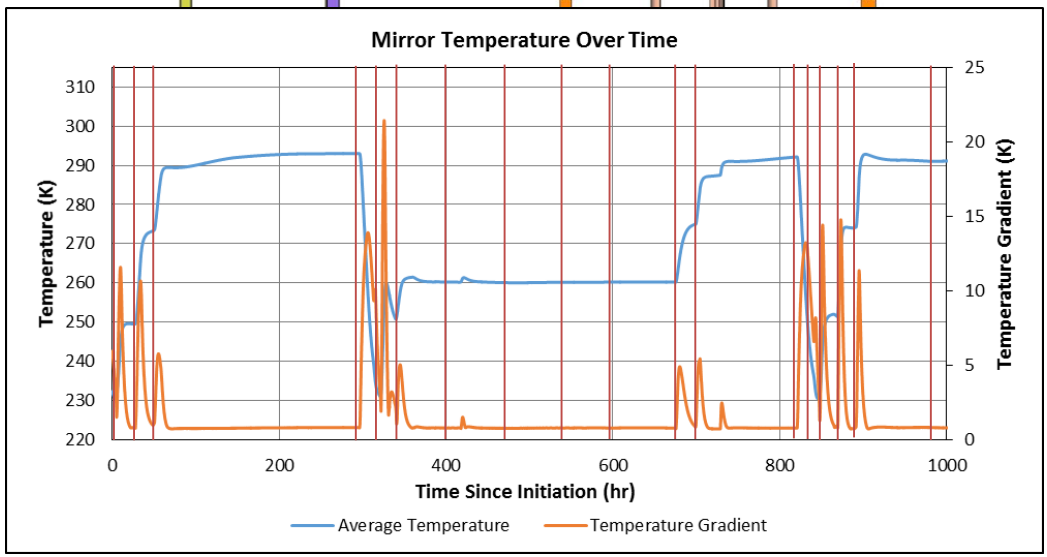
Measured – Analysis
5.9 nm < repeatability

Optothermal test of ULE Mirror

1.45m Zerodur Mirror
1.34m measured aperture
0.173m and 0.176m thick at the ID and OD respectively



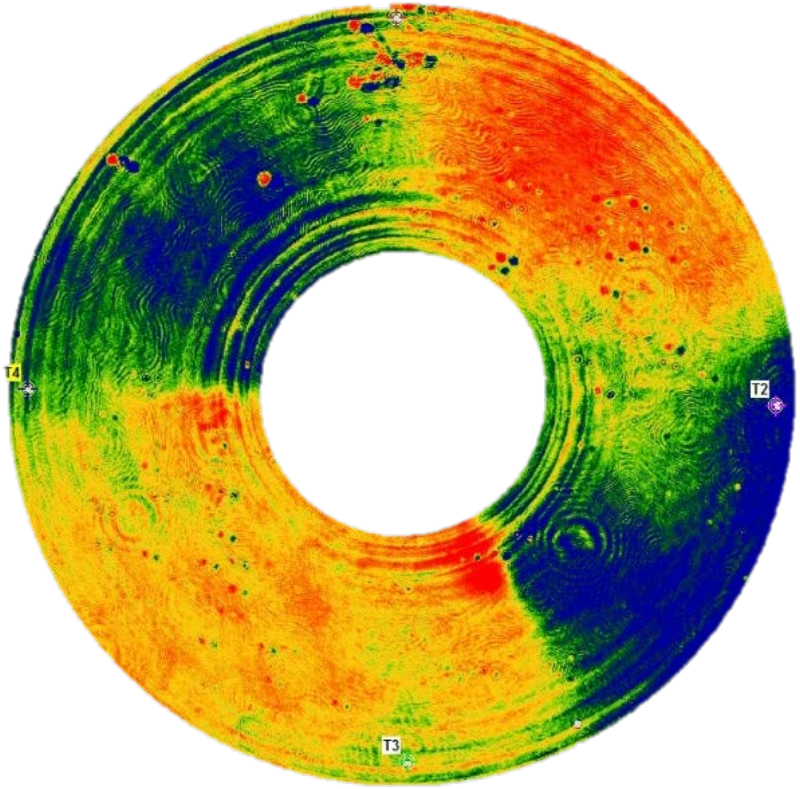


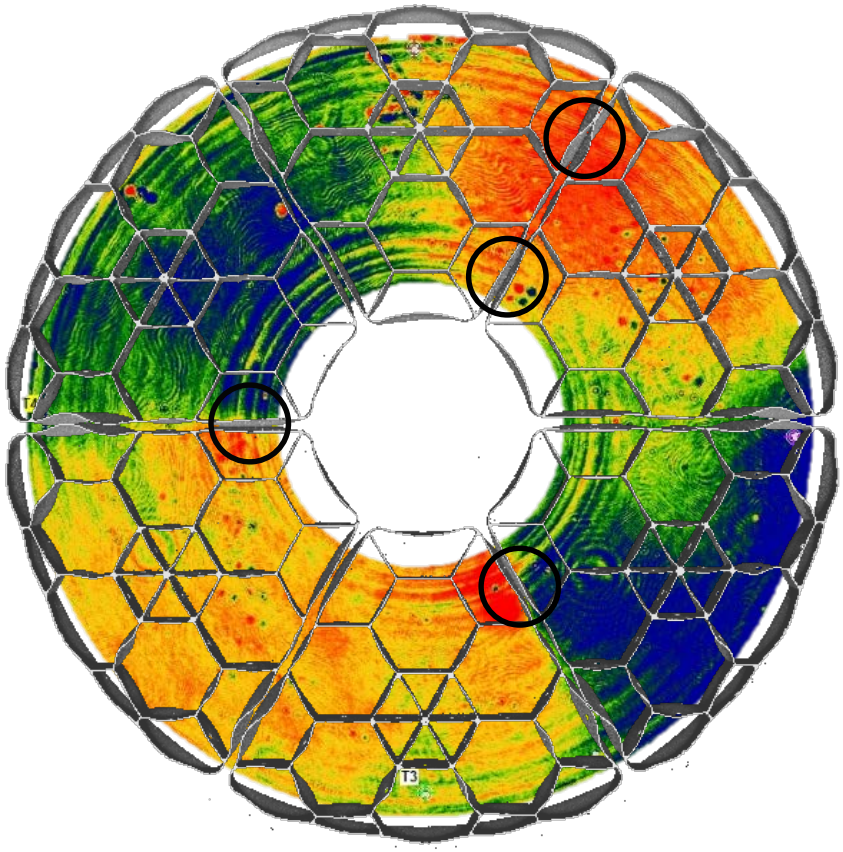


- Surface figure measurements taken at 292, 275, 260, 250 and 230K.
- 3 cycles performed due to a stiction event

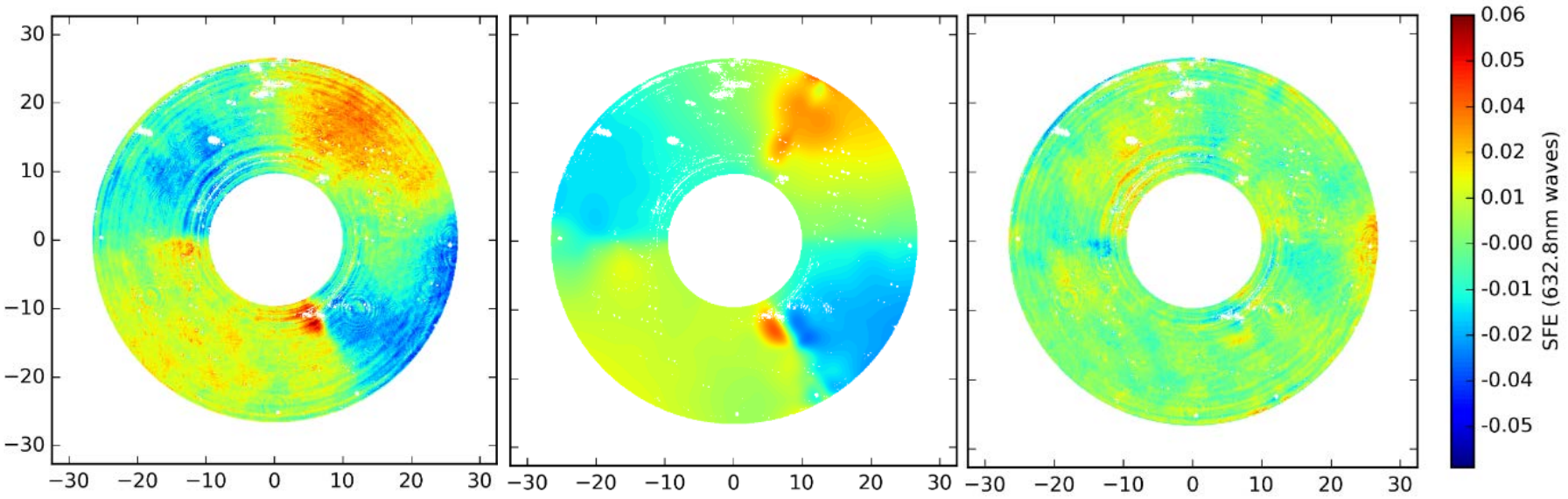
Hysteresis Compared to PCRs

- Computed Tomography (CT) Scan turned into Mirror FEM.
- Potentially Contact Ribs (PCRs) present near all of the hysteresis hotspots.
- Hypothesis: Rib-rib stiction is responsible for the hysteresis.





Rib to rib stiction



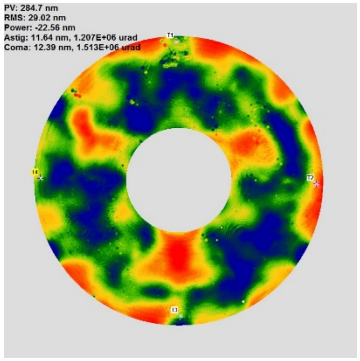
Surface hysteresis over cycle 1
10.8 nm RMS

Surface forces applied at rib-rib stiction
9.4 nm RMS

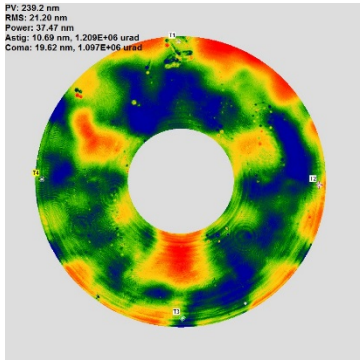
Surface forces applied at rib-rib stiction
5.2 nm RMS

- Test Measurement Repeatability ~6nm
- Residual SFE < Test Repeatability: therefore, model considered correlated
- **Rib-rib stiction is likely culprit of the hysteresis**

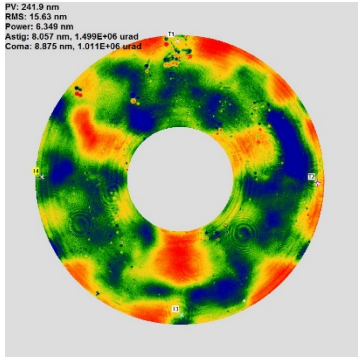
ULE Mirror Cryo-Deformation



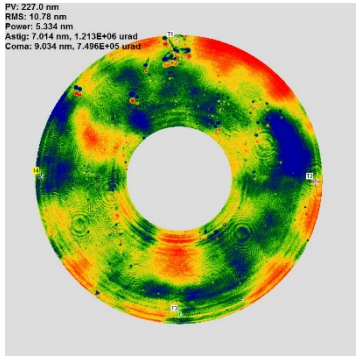
dT=62 ˚C
29.2 nm RMS



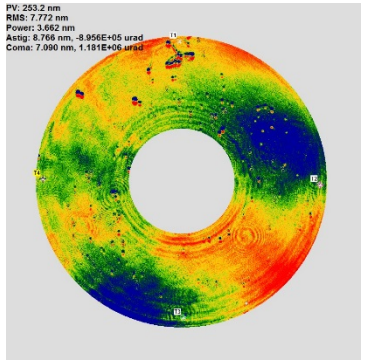
dT=42 ˚C
21.2 nm RMS



dT=33 ˚C
15.6 nm RMS

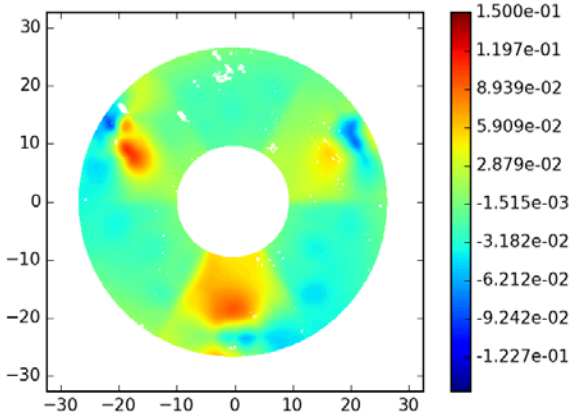


dT=18 ˚C
10.8 nm RMS

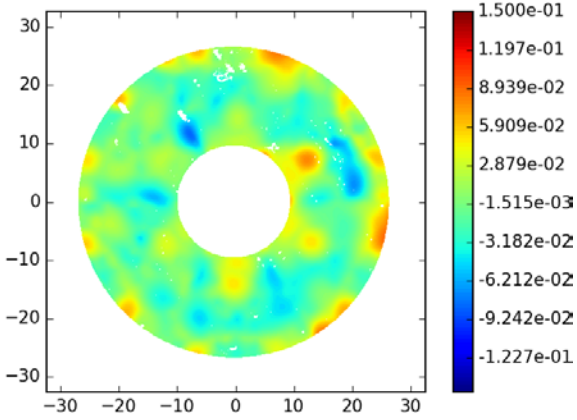


dT=1 ˚C
7.8 nm RMS

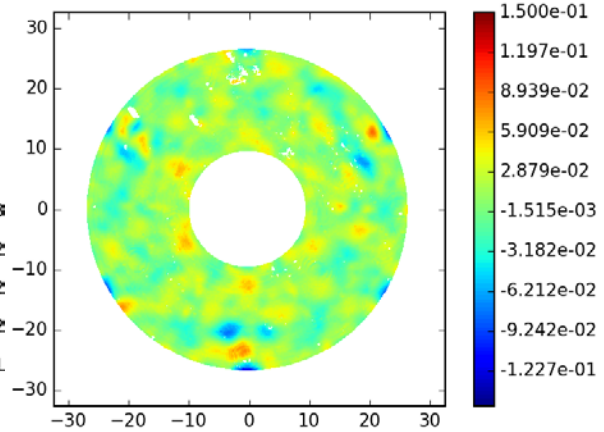
Large mount effects are evident. An attempt was made to separate mount effects and inhomogeneity effects and the results of that are shown below.



Mount effect
18.9nm RMS



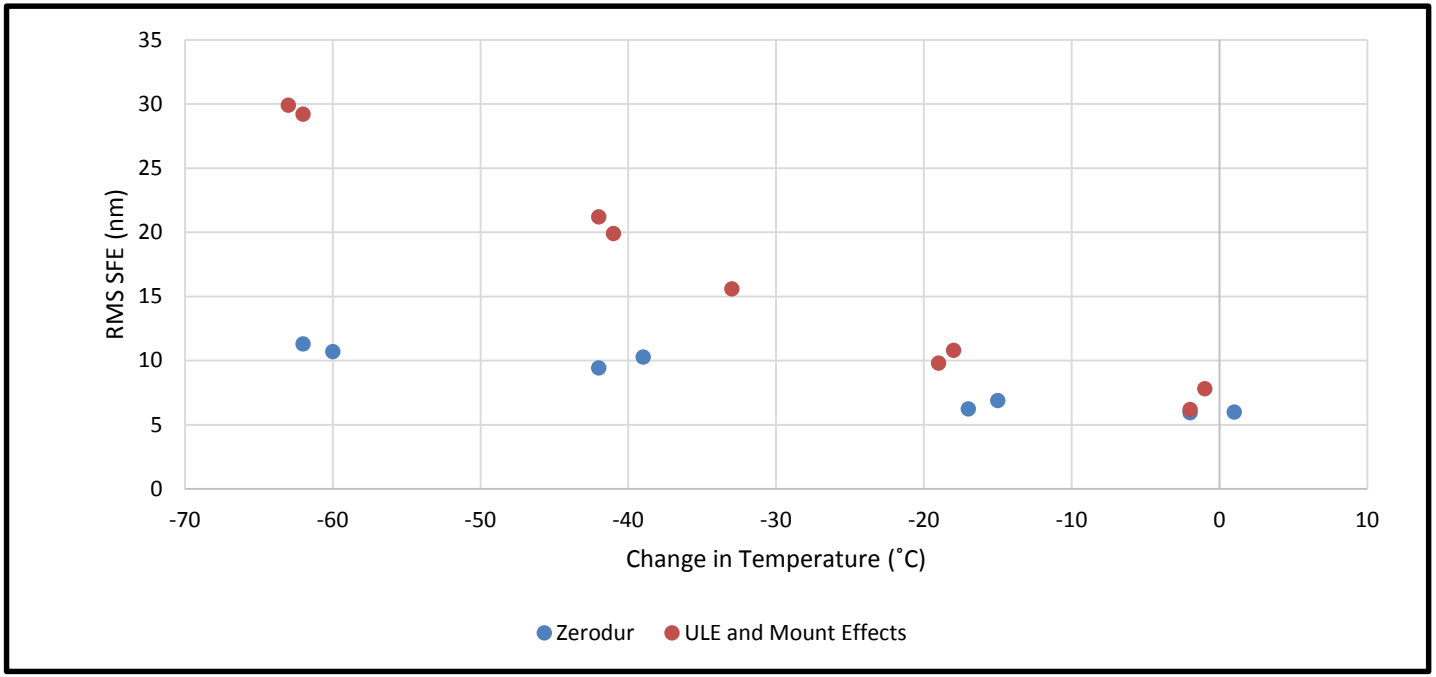
Inhomogeneity effect
16.6nm RMS



Residual Error
13.4nm RMS

Comparing Zerodur & ULE Tests

Summary: The ULE mirror changed 0.27nm/˚C (after mount effects are subtracted) and the Zerodur mirror changed 0.18nm/˚C. These are the recommended values to use, and they are conservative.



Notes:

1. The ULE test includes a large contribution from the mount while the Zerodur test does not.
2. The ULE mirror was made using an experimental process and may not be representative of all ULE mirrors.
3. The Zerodur mount is very compliant and may or may not be able to survive launch loads with appropriate vibration isolation and launch locks.
4. The repeatability of the Zerodur test was ~6nm and the repeatability of the ULE test was ~8nm.

Comparing Materials

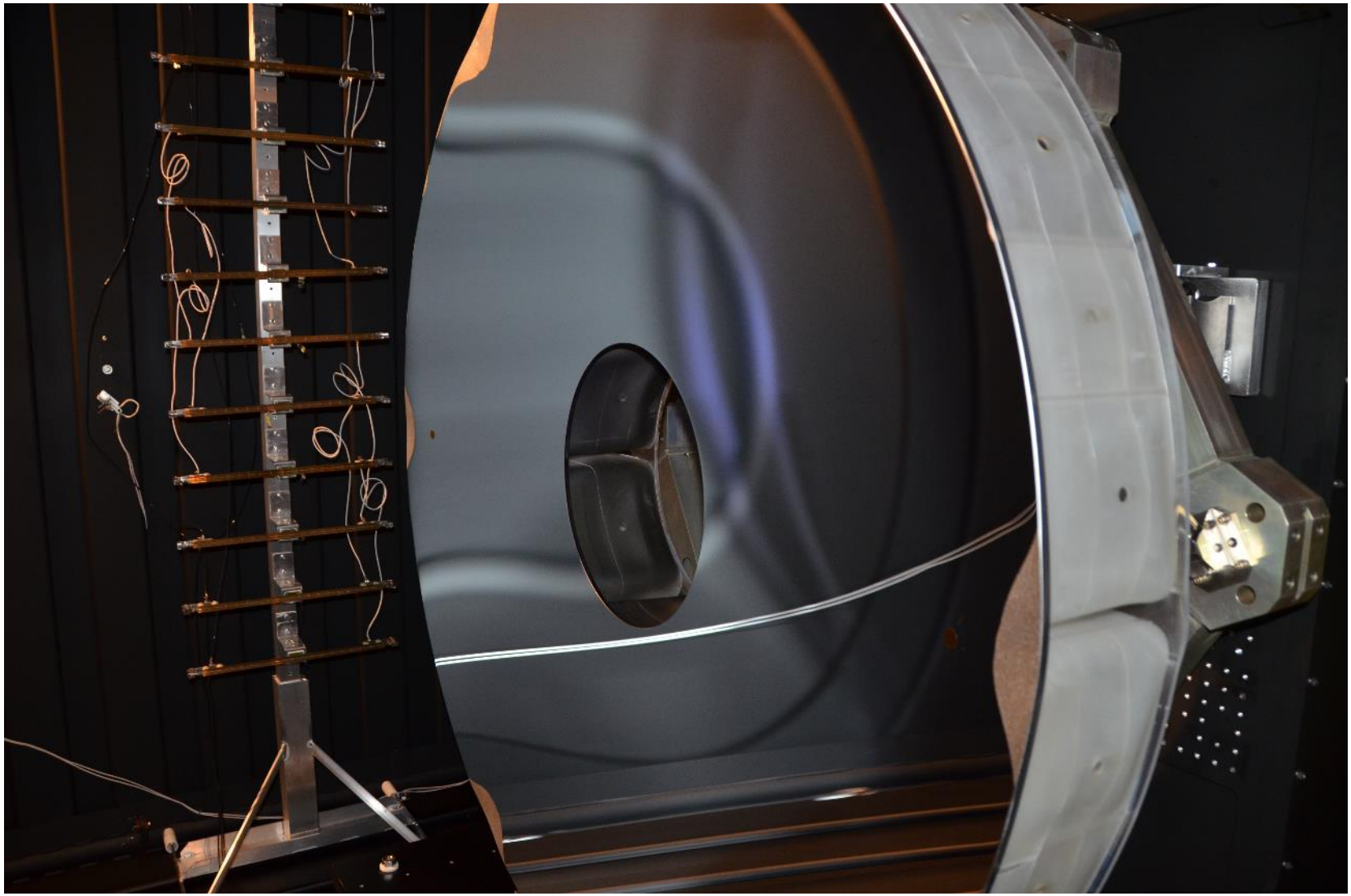
Material	Measured Aperture (m)	Mirror Diameter (m)	Mirror Thickness at mirror ID/OD (m)	Change in RMS Surface per Temperature (nm / ˚C)
Zerodur	1.06	1.2	0.071/0.124	0.17†
ULE	1.34	1.45	0.173/0.176	0.48†
"CERAFORM" SiC	0.51	0.51	0.059	0.23*
"SuperSiC" SiC	0.25	0.25	0.035	0.105‡

† Sensitivity estimated with a soak between 293 and 230K
* Sensitivity estimated with a soak between 293 and 150K
‡ Sensitivity estimated with a soak between 293 and 196K

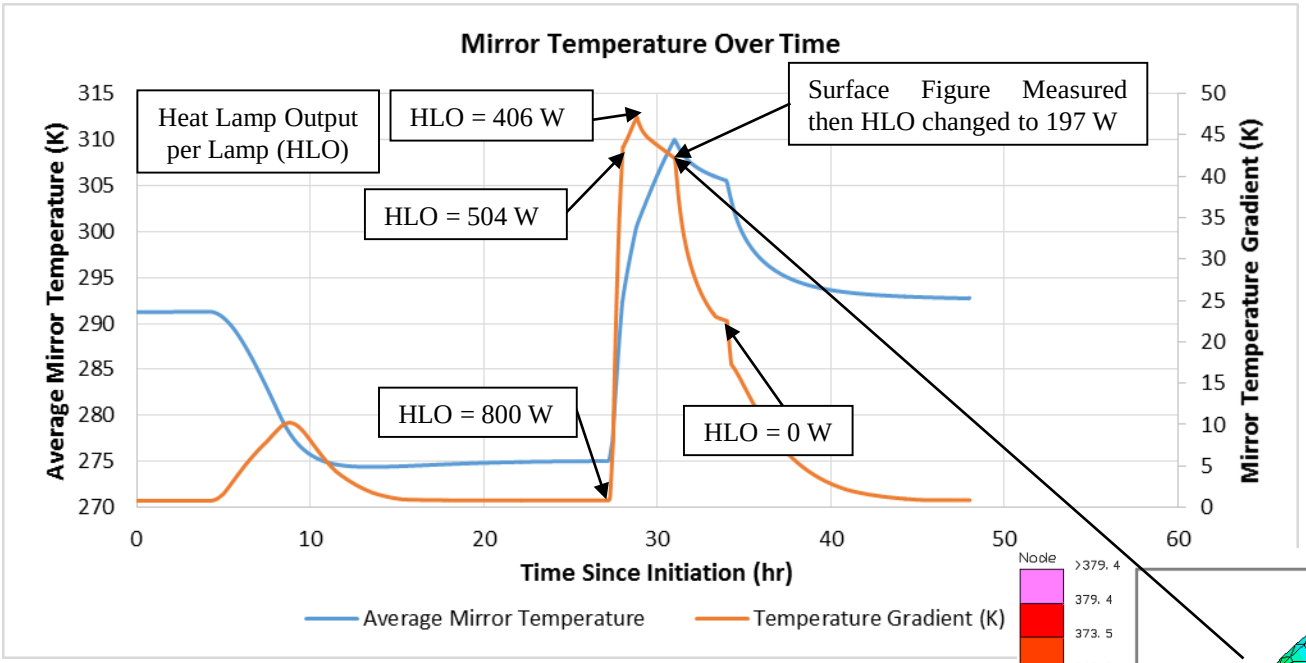
Notes:

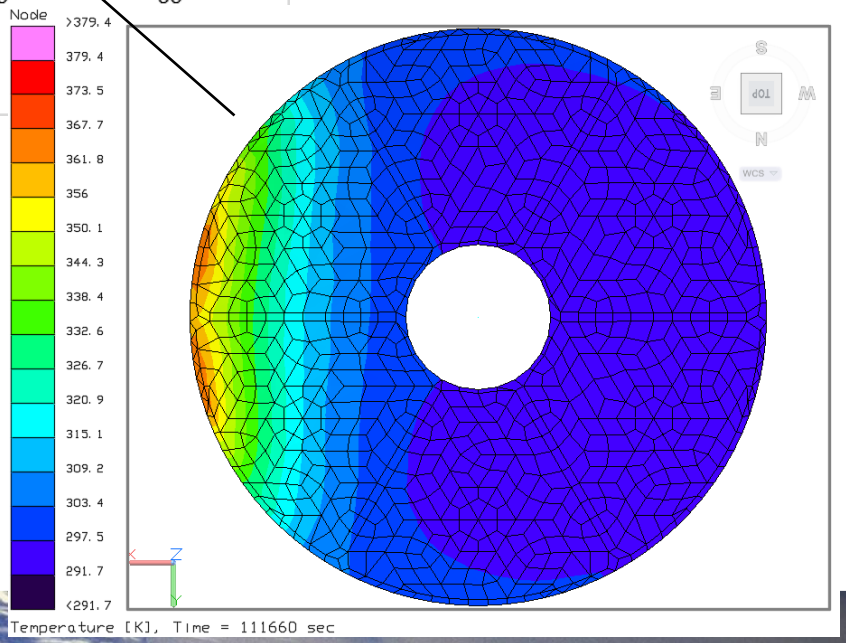
1. The ULE test includes a large contribution from the mount while the Zerodur test does not.
2. The ULE mirror was made using an experimental process and may not be representative of all ULE mirrors.
3. The Zerodur mount is very compliant and may or may not be able to survive launch loads with appropriate vibration isolation and launch locks.
4. The repeatability of the Zerodur test was ~6nm and the repeatability of the ULE test was ~8nm.

ULE Mirror Thermal Gradient Test



ULE Mirror Thermal Gradient Test

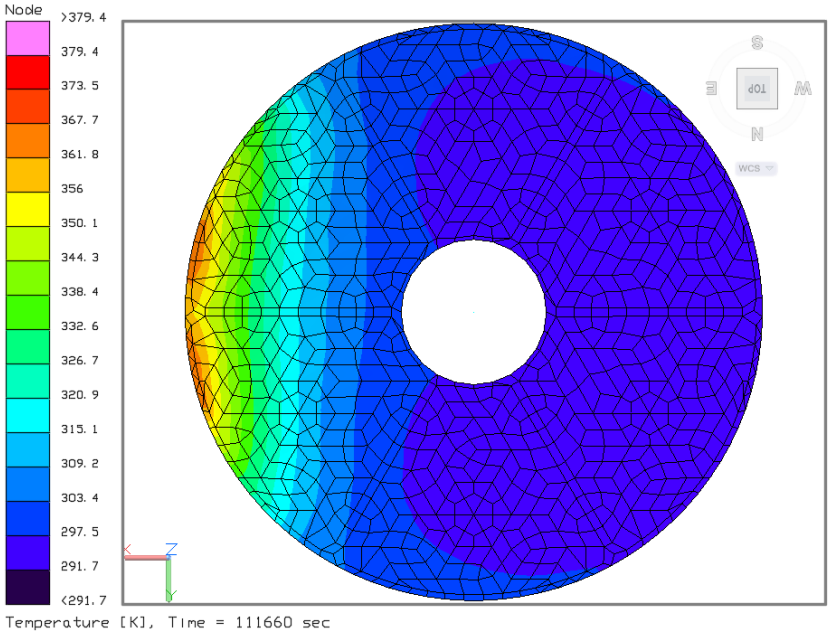




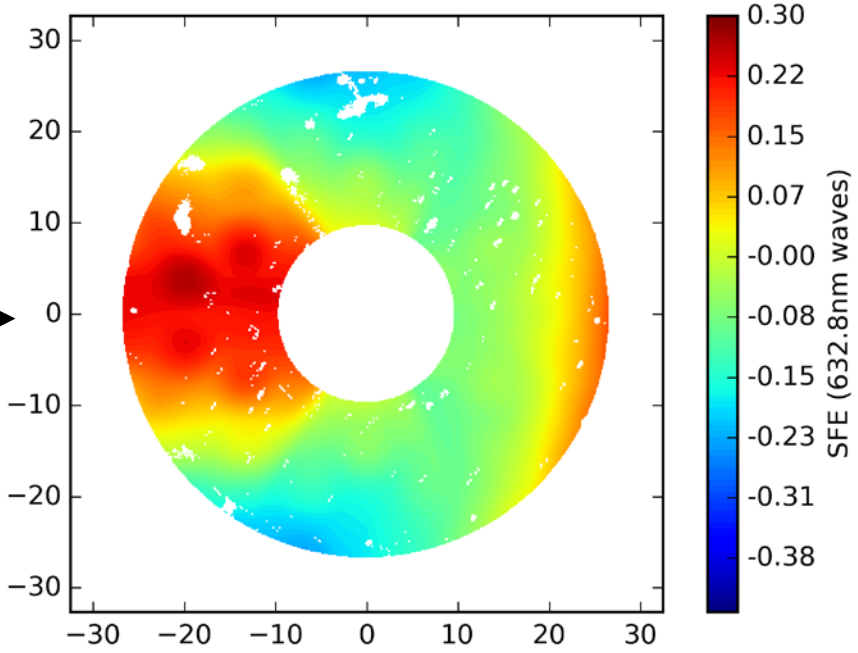
Analysis and temperature measurements combined to estimate the temperature distribution throughout the entire mirror.

ULE Mirror Thermal Gradient Test

Thermal Gradient
ΔT = 87.7 K Peak-to-Valley

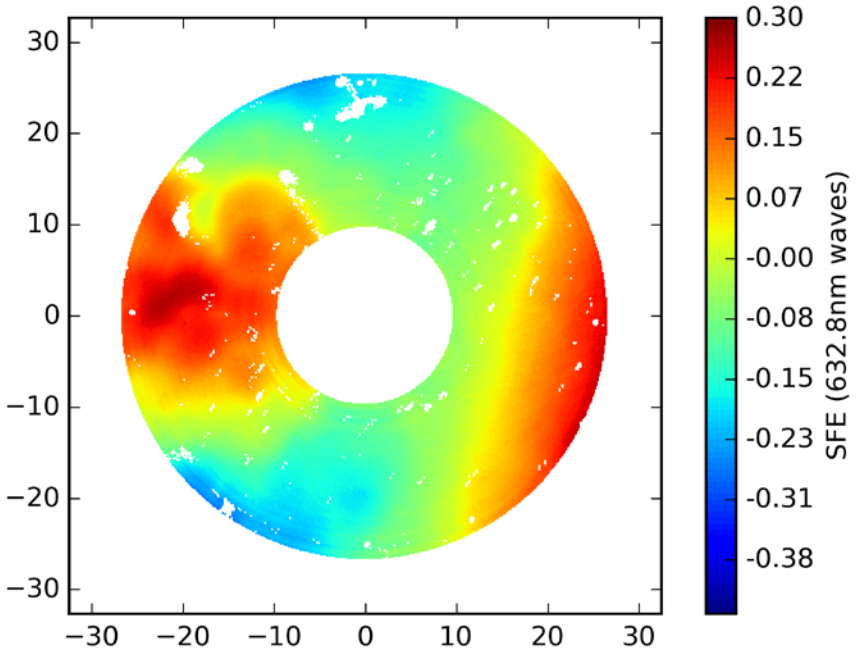


Analysis Result
RMS SFE = 78.5 nm

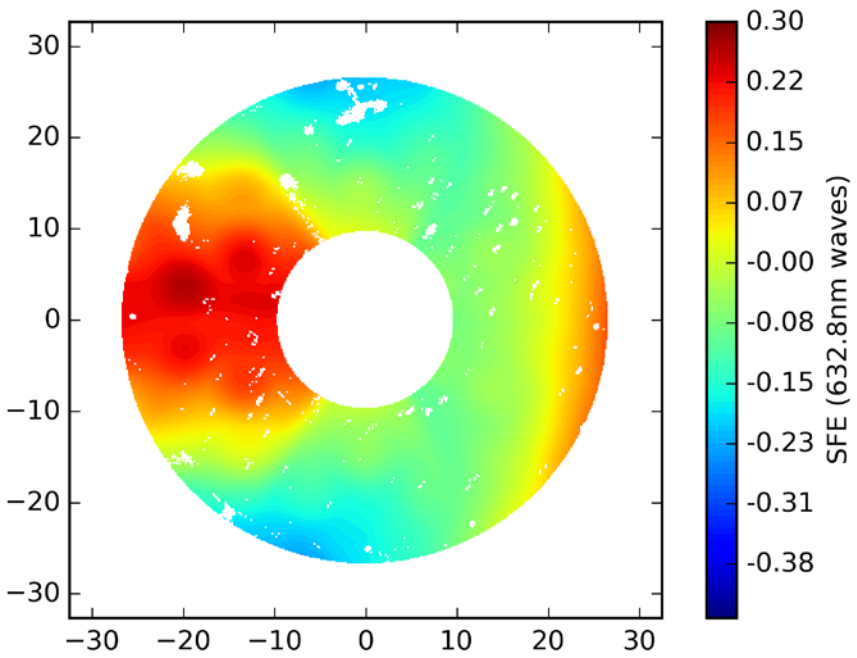


Gradient Test and Analysis Results

Test Result
RMS SFE = 78.5 nm



Analysis Result
RMS SFE = 78.5 nm



- This ULE mirror's temperature was elevated during manufacture which probably affected its CTE.
- RMS SFE matched by scaling the CTE of ULE to 81ppb/K.

Questions?